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# THE FEASIBILITY OF USING RUBBLE MASONRY CONCRETE ON DAM STRUCTURES DURING DAM REHABILITATION IN SOUTH AFRICA TO INCREASE PRODUCTIVE LABOUR OPPORTUNITIES

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the degree of
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**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

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**Research Report:**

# The feasibility of using rubble masonry concrete on dam structures during dam rehabilitation in South Africa to increase productive labour opportunities


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**Promoter**: Prof. RT McCutcheon


SUBMISSION DATE: 28 February 2013

## Declaration

I declare that this research report is my own, unaided work. It is being submitted in partial fulfilment of the requirements for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any University.

…….....……

**Ivor Charl Segers**

28 February 2013

## Abstract

Unemployment is currently at a high level in South Africa. The Dam Safety Rehabilitation Programme was started in 2005 with the aim of rehabilitating dams belonging to the Department of Water Affairs. Within the ambit of this programme, 33 dams have been rehabilitated as at December 2012, with a further two dams scheduled for completion at the end of March 2013. Several rehabilitation projects have been completed using labour-intensive methods as opposed to conventional construction methods. The labour-intensive methods used on the dam rehabilitation projects include the use of rubble masonry concrete and brickwork as opposed to using conventional construction methods, for example, mass- and reinforced concrete. The aim of the research is to probe the impact of the labour-intensive rehabilitation methods as compared with conventional construction methods. Five dam rehabilitation projects were investigated for this project. Three rubble masonry concrete dam rehabilitation projects were researched in Limpopo Province, namely, Molepo Dam (spillway), Chuniespoort Dam (spillway and parapet wall) and Mashashane Dam (spillway). Two other dam rehabilitation projects were included for comparison purposes: Klein Maricopoort Dam (in North West Province), a conventional concrete spillway project, and Albert Falls Dam (in KwaZulu-Natal), a brick parapet wall project. This research explores three key areas, namely, production rates, cost and productivity. The findings of the research may be generalisable to other labour-intensive construction on dam rehabilitation projects. The findings indicate that production rates (man-hours/$m^3$), decrease with larger volumes of rubble masonry concrete placed. When comparing rubble masonry concrete construction with conventional concrete construction, there is an increase in job opportunities created. The costs of construction using rubble masonry concrete compared with conventional concrete using the same in-house public sector contractor were similar in terms of ZAR per $m^3$. The rubble masonry concrete structure constructed by the private sector contractor cost less than the rubble masonry concrete structures constructed by the in-house public sector contractor in terms of ZAR per $m^3$. Various reasons for the price difference are identified in the research project. Productivity ($m^3$/person/day) was measured for the different rubble masonry concrete sites and it was found that the private contractor's productivity rate was well above the productivity rates of the in-

house public sector contractor's projects. The research report highlights various reasons to explain this anomaly. The importance of an incentive scheme to boost productivity on a labour-intensive project is highlighted. The findings of this research project may provide a guide for future decision making into the use of labour-intensive constructive methods for dam rehabilitation. The research concludes that labour-intensive rehabilitation of dams should be continued since it results in a technically sound and cost-competitive product and creates more productive labour opportunities per unit of expenditure.

**Keywords**

In-house contractor rubble masonry concrete dam construction
Public sector contractor rubble masonry concrete dam construction
Private sector contractor rubble masonry concrete dam construction
Labour-intensive methods of dam construction
Labour-intensive rubble masonry concrete dam construction
Productivity of labour-intensive methods of dam construction

This research report is dedicated to my parents, Jack and Ivy,
who instilled in me a love of learning

and

to my wife, Janice, and daughter, Jemma,
who unselfishly allowed me the time to expand my knowledge.

*"Let there be **work**, bread, **water** and salt for all"* – Nelson Mandela

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## Abbreviations

| | |
|---|---|
| CIDB | Construction Industry Development Board |
| DWA | Department of Water Affairs |
| IBRD | International Bank for Reconstruction and Development |
| NDP | National Development Plan |
| RMC | Rubble masonry concrete |

# 1 Introduction

Unemployment is a growing concern around the world. The Engineering News of 12 October 2012 (Creamer, 2012:26) states

> currently more than three billion people are working globally, with 1.65 billion of those individuals receiving regular wages or salaries. Another 1.5 billion work in farming and small household enterprises, or do casual or seasonal day labour.

The article continues:

> some 200 million people, 75 million of them being youth, are unemployed, while actively looking for work. A further two billion working-age adults, the majority of them women, are neither working nor looking for work (p.26).

According to the article,

> in the current low job-growth environment, is a calculation showing that, by 2020, there needs to be around 600-million more jobs than in 2005 simply to keep employment as a share of the working-age population constant (p.26).

In South Africa there is a shortage of employment opportunities. For Census 2011 two definitions were used to describe the unemployed (Census 2011, 2012:41). Firstly they use the *official definition*: “Persons who did not work, but who looked for work and were available to work in the reference period.” Secondly they refer to the *expanded definition*: “Persons who did not work, but were available to work in the reference period.”

The latest census confirms that South Africa has a serious unemployment issue. Using the official definition, South Africa’s unemployment was 30 % in 2011. However, if one uses the expanded definition, unemployment in South Africa was 40 % in 2011. The reference period for employment figures in Census 2011 was fixed for the week before the census night – 09 October 2011 (Census 2011, 2012:41). Unemployment can be broken down into provinces which shows that, using the expanded definition, unemployment varies between 30 % in the Western Cape to 50 % in the Limpopo and Eastern Cape provinces. The three rubble masonry concrete (RMC) case studies used in this research project are located in Limpopo Province. Census 2011 (2012:41) reflects that Limpopo Province had the highest

unemployment rate (38.9 %) according to the official definition and the second-highest unemployment rate (49.9 %) according to the expanded definition. Measured according to the 4th Quarter 2011 Quarterly Labour Force Survey (Census 2011, 2012:43), the figures are 20.2 % and 44.7 %, respectively, for the official and expanded unemployment definitions.

Census 2011 (2012:45) also highlights the fact that according to the official definition, 30.5 % (expanded definition: 39.8 %) of Black African men are unemployed and 41.2 % (expanded definition: 52.9 %) of Black African women are unemployed, compared with 5 % (expanded definition: 8.1 %) of White men and 6.9 % (expanded definition: 12.5 %) of White women who are unemployed. Census 2011 (2012) also shows that the unemployment rate among youth aged 15 years to 24 years is higher than for older age groups.

Kane-Berman (2013), Chief Executive of the South African Institute of Race Relations, sums up the unemployment situation as follows in the *Business Day* article "State in denial of despair of jobless as it threatens employers" of 21 January 2013:

> At the end of last year [(2012], 150 000 people applied for 90 trainee traffic police jobs in KwaZulu-Natal, of whom 34 000 were short-listed and 15 500 aged between 18 and 20 arrived in Pietermaritzburg, where seven died during fitness tests, evidently of heat exhaustion. In September 10 000 people queued for 30 Transnet jobs in Bloemfontein. In February 2011, 30 000 people converged on Polokwane for 624 government jobs on offer. In September 2009, thousands showed up in Durban for 200 learner police jobs.

The government of South Africa recognises the need to improve the status quo relating to job creation. President Zuma's *State of the Nation* speech in February 2012 focused on unemployment, poverty and inequality. According to President Zuma, 365 000 people were employed in new jobs during 2011 which marked the country's best performance since the recession of 2008 (Zuma, 2012). He stated that job creation was "mainstreamed in every government entity including state-owned enterprises." President Zuma mentioned that social dialogue was strengthened "between government, business and the community sector" and said that government is inviting the nation to join them in a "massive

infrastructure development drive" beyond 2012 which will boost the level of economy and create job opportunities.

The National Development Plan 2030 was commissioned by the National Planning Commission (NDP, 2012) which is a branch reporting to the South African Presidency. The National Development Plan is described as

> A plan for South Africa to eliminate poverty and reduce inequality by 2030 through uniting South Africans, unleashing the energies of its citizens, growing an inclusive economy, building capabilities, enhancing the capability of the State and leaders working together to solve complex problems (p.1).

Chapter 3 of the National Development Plan (NDP, 2012) deals with the economy and unemployment. The plan acknowledges that, to eliminate poverty and reduce inequality, South Africa has to raise levels of employment and, through productivity growth, the earnings of working people.

The National Development Plan (NDP, 2012) and the State of the Nation address (Zuma, 2012) state that the New Growth Path is government's key programme to take the country onto a higher growth trajectory. The New Growth Path is about

> creating the conditions for faster growth and employment through government investment, micro-economic reforms that lower the costs of business (and for poor households), competitive and equitable wage structures, and the effective unblocking of constraints to investment in specific sectors (NDP, 2012:117).

The National Planning Commission's National Development Plan (NDP, 2012:117) states the following high-level numeric targets for sustainable and inclusive growth:

- A fall in the strict unemployment rate from 25 % to 14 % in 2020 to 6 % by 2030
- A rise in the labour force participation rate from 54 % in 2010 to 65 %
- About 11 million additional jobs by 2030.

Elsewhere, the National Development Plan (NDP, 2012) also states that public employment schemes will be an essential part of an employment plan to 2030. The main opportunities will lie in community-based services and the roll-out of the social-sector initiatives of the Expanded Public Works

Programme. The plan states that, realistically, South Africa must plan and budget for a minimum of two million opportunities annually. The Expanded Public Works Programme Phase I started in April 2004 and ended in March 2009. During the first five years of the EPWP, according to McCutcheon and Taylor Parkins (2012):

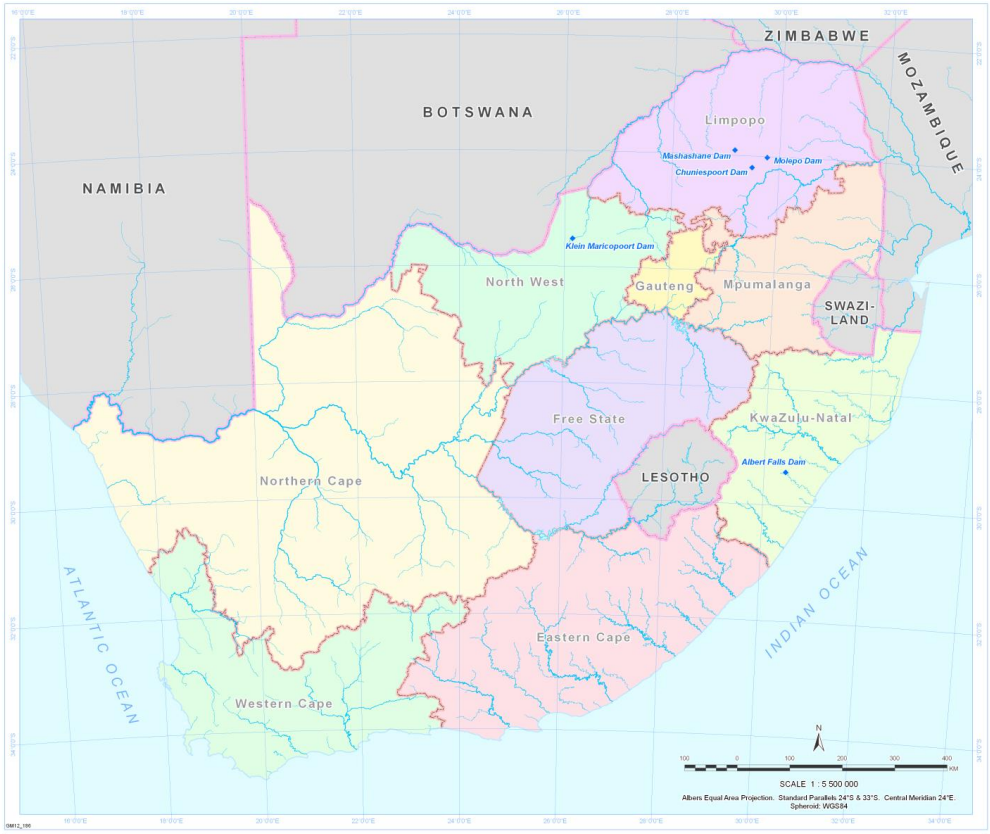
> there was a steady decline in labour intensity from 26 % at the start of 2004 to nearly 11.3 % at the end of the fourth quarter of the 2008/09 financial year (p.39).

The article compares the labour intensity to similar programmes in "Botswana and Kenya where labour intensities of over 50 % were achieved using relatively low wage rates" (p.42). The article concludes:

> if a proper programme not be established, the second phase of the Expanded Public Works Programme will be just as inefficient in generating a significant increase in effective work opportunities amongst the poor, particularly the rural poor, during the provision of public infrastructure (McCutcheon and Taylor Parkins, 2012:45).

The above picture painted about unemployment in South Africa shows that there is a need to create jobs in this country and that current and future infrastructure programmes funded with fiscus capital can play a role in relieving the high unemployment rate. The National Department of Water Affairs embarked on a rehabilitation programme for its dam infrastructure in order for the dams to comply with international dam safety standards. The Dam Safety Rehabilitation Programme started in 2005/6 to eliminate the backlog of maintenance and rehabilitation issues of infrastructure belonging to the Department of Water Affairs. As at December 2012 more than ZAR1.7 bn has been spent on dam safety rehabilitation-related work countrywide. The majority of dam rehabilitation projects are as a result of insufficient spillway capacities. The problems of insufficient spillway capacities are due mainly to not having long enough hydrological records during the original design of the dams. Altogether 33 dams have been rehabilitated with a number of other dams in different stages of design. Most of the dams have been constructed using conventional dam engineering and construction methods. At four dams, the use of labour-intensive construction methods has been tried. These dams are Molepo Dam (Limpopo Province),

Chuniespoort Dam (Limpopo Province), Mashashane Dam (Limpopo Province) and Albert Falls Dam (KwaZulu-Natal). The location of these dams is shown in Figure 1.1.




Source: Department of Water Affairs Directorate Spatial Land Information Management

**Figure 1.1: Location of Dam Safety Rehabilitation Programme dams**

It is interesting to note that in South Africa the roll-out of infrastructure spending, specifically on dams, to combat unemployment has been executed in the past, regardless of the costs. van Vuuren (2012:106) notes that in South Africa the 'poor white' problem was becoming a political quagmire between the two World Wars. A combination of the Depression and droughts in South Africa

> compounded the 'poor white' problem, and the government of the day responded by announcing the construction of large State infrastructure schemes (including dams and canals), which would set out to employ large numbers of white labour. At the height of the State's intervention, relief measures made up approximately 16 % of the national budget. Public works schemes provided some training for unskilled labourers, educated and trained their children and provided free housing and medical services.

van Vuuren (2012:107) goes on to assert:

> a number of irrigation projects that had been considered for many years without action were suddenly fast-tracked, including the Buchuberg Irrigation Scheme, the Loskop Irrigation Scheme and the Vaal River Development Scheme, which would lead to the development of the largest irrigation scheme in South Africa (Vaalharts) and the country's strategically most important dam (Vaal Dam).

van Vuuren (2012:108) quotes the Director of Irrigation, AD Lewis, writing in the Annual Report for that year:

> The experience of this department is that where white labour is being used expenditure is very high, for example, to keep an average workforce of 360 [such as on the Rust-de-Winter irrigation scheme – *also rehabilitated as part of the Dam Safety Rehabilitation Programme's 33 completed rehabilitated dams*] requires recruitment of more than 1 550 workers.

Van Vuuren (2012) notes that in cases where labourers were well fed their output improved. At many sites meals were initially provided at low cost. Subsequently meals were supplied free of charge.

## 1.1 Aim of the research

This research project aims to probe the consequences of implementing labour-intensive construction methods on the Department of Water Affairs' Dam Safety Rehabilitation Programme as opposed to the use of conventional construction methods. The findings of this research project may provide a guide for future decision making into the use of labour-intensive constructive methods for dam rehabilitation.

## 1.2 Generalisability of the research

The four labour-intensive dam rehabilitation projects studied in this research are the only designated labour-intensive dam rehabilitation projects carried out by the Department of Water Affairs in South Africa. As far as the researcher is aware, the information obtained from this comparative study has not been documented previously and thus it may be used as a baseline study against which to assess labour-intensive dam rehabilitation projects being undertaken elsewhere in South Africa.

## 1.3 Structure of the research report

Having provided the background to the research in Chapter 1, a literature review is presented in Chapter 2. Chapter 3 contains the research methodology and probes the cost implications where labour-intensive methods of construction were used and whether they had any positive impact on the creation of job opportunities. The findings of the research are also presented in Chapter 3. These findings and lessons learnt from labour-intensive projects are discussed in Chapter 4. Chapter 5 contains the conclusions and recommendations for further research. A list of the references used is provided at the end of the document.

- - - oOo - - -

Chapter 1 contained an introduction to the research, the aim of the research, the generalisabiity of the results and a description of the structure of the document. The next chapter contains the literature review.

# 2 Literature review

The background information to the research was presented in Chapter 1. Chapter 2 contains a review of literature salient to the research.

## 2.1 Labour-intensive construction: definition and objectives

McCutcheon (2003:21) notes the term “labour-intensive construction” has been developed and can be described as

> economically efficient employment of as great a proportion of labour as is technically feasible – ideally throughout the construction process, including the production of materials – to produce as high a standard of product as demanded by the specification and allowed by the funding available.

McCutcheon (2003:21) asserts the result is a “significant increase in employment opportunities per unit of expenditure by comparison with conventional capital-intensive methods”. McCutcheon (2012) extends this definition to include “… without compromising time, cost and quality, once the systems have been established.”

McCutcheon (2003:21,22) opines:

> essentially employment-intensive construction has three main objectives:
>
> - A technically sound (good quality), economically efficient product: equivalent to that achieved by conventional construction without jeopardising economic cost, time and quality;
> - A significant increase in the use of labour per unit of expenditure, and
> - The greater use of these methods within the whole contracting industry (the major contractors in order to generate large numbers of productive jobs as soon as possible; the small contractors in order to fulfil government objectives with respect to development in relation to previously disenfranchised/black economic empowerment and generate as much productive employment as possible, bearing in mind the extremely small proportion of the overall expenditure on civil construction which is carried out by small contractors).

The use of labour-intensive construction methods remains debatable and many engineers are still reluctant to use these methods. As far back as 1986,

the International Bank for Reconstruction and Development (IBRD) (now the World Bank) (IBRD, 1986:1) cited the following reasons for the reluctance to use labour-intensive construction methods:

- fears of poor quality of the finished work,
- fears of slow progress in executing the construction work,
- concern about the need to make special organisational arrangements, and
- concern that the costs would be higher than those of equipment-intensive operations.

These concerns are still evident in 2013, which is why the researcher undertook this research project in order to better understand the social and economic impact of RMC as a material in the construction or rehabilitation of dams.

Phillips *et al*. (1995) wrote a paper entitled: "*Technical analysis of the employment creation potential of a National Public Works Programme*" which describes the work and conclusion of a Technical Focus Group researching methods to increase labour intensity. Many of the points mentioned in the paper are still relevant in 2013 with regards to training, small contractor development programmes and appropriate materials and designs for labour-intensive construction. The paper highlighted different infrastructure sectors in which labour-intensive construction methods could be used. One such area highlighted is dams. The paper states (p.20):

> the potential labour content of dam construction projects is dependent on the choice of dam site as well as the type of structure.

Phillips *et al*. (1995:20) also note:

> many existing South African dams offer irrefutable proof that dams constructed with a minimum of heavy machinery are in no way inferior to their counterparts from the mechanisation era.

Finally these authors assert (1995:20):

> labour-intensive construction of small dams should act as a springboard for developing the capacity to reinstate labour-intensive construction of large dams.

Phillips *et al*.'s (1995) Technical Focus Group then categorises the sectors into different groups and allocated dams to Group 4. "Group 4" is described as:

> Projects that are presently machine-intensive. However, theoretical research regarding the reintroduction of labour-intensive production methods has largely been carried out and there is some recent history of attempts to reintroduce labour-intensive techniques in South Africa. Nevertheless, there is a need to compile training material at a national level, to carry out pilot projects, to disseminate guidelines and to institute training programmes.

Group 4 was further characterised by a "medium-high" skills requirement and a labour intensity of "low, but starting to increase". The current spending on labour at dams was approximated as 10 to 20 % and it was envisaged that the maximum spending would increase to 50 to 80 %.

## 2.2 The history of rubble masonry concrete, the emergence of conventional concrete and the rebirth of rubble masonry concrete

According to the Construction Industry Development Board (CIDB), mankind has used RMC as a material for the construction of dams for many years.

> Although it has been partially washed away, the oldest dam wall still standing was constructed using stone and gravel enclosed in a skin of uncemented rubble masonry. Sadd el-Kafara Dam, constructed circa 4500 BC approximately 30 km to the south of Cairo in Egypt, stands over 11 m in height. In all probability, this dam failed soon after completion as a consequence of inadequate spillway capacity (CIDB, 2005:3).

CIDB (2005:3) notes that another example of a masonry dam, the Alicante Dam in Spain, was completed in 1594 to a height of 43 m, and for almost 300 years was the highest dam in the world. Emphasising the durability of masonry, CIDB (2005:3) asserts:

> With the advent of rational design methods, strong and durable masonry gravity dams were consistently being produced by the middle of the 19$^{th}$ century and the majority of these remain standing today.

There was, however, a revolution in the way modern structures evolved in such a manner that RMC became almost redundant.

Rankine (2000:2.2) states:

> engineers such as Rankine (1865), Krantz, De Sazilly, Delocre and Levy began to question the material properties of RMC and apply rational design philosophies to its structural use. ...The building of the Panama Canal in the first decade of this [20th] century … [with a] volume of 3.7 million $m^3$ of concrete

however started the revolution away from RMC to what is now known as "conventional concrete". Rankine (2000:2.3) notes:

> The accompanying developments in machinery greatly reduced the cost of crushed aggregate and cement and significantly improved the quality of the latter. Coupled with an increasing cost of labour and a desire to reduce construction time, these factors brought about the evolution of a new material called "cyclopean masonry" to replace RMC for dams.

Rankine (2000:2.4) states

> during the next decade concrete became even less costly and the tradition of carefully placing large cyclopean inclusions gave way to a new practice of dumping "plums" into concrete to enhance its economy – a material dubbed "concrete masonry" by the Americans.

Rankine (2000:2.4) asserts

> shortly thereafter, "unadulterated concrete", as we know it today, became the norm. Not only could concrete structures be built in less time and at lower construction cost using crushed aggregates and batching plants, but small concrete specimens (typically cylindrical or cubic prisms) could be routinely tested to confirm the concrete's strength and variability. Upon this quantified knowledge, the basis or rational design of more efficient and economical concrete structures of known reliability was founded. Uncertainty as to the possible deleterious effects of dumping large plums into concrete resulted in their prohibition in applications of structural significance by many design codes. Consequently, the pursuit of knowledge about the mechanical properties, behaviour and engineering use of RMC drew to a halt.

King (1994:12) cites Wegmann who in 1911 opined:

> Most dams built at the end of the last [19th] century and the beginning of this century (20th century) were of cyclopean masonry in which "plums" or "spalls" were partially embedded in a very wet concrete.

King (1994:12) notes: "the spaces between plums were then filled with concrete, also very wet." The Theodore Roosevelt Dam, built between 1905 and 1911 in the USA, remains the tallest masonry dam in the world. King

(1994:12) asserts “approximately 70 % of the final construction costs went towards the labour component”.

The CIDB (2005:3) also echoes the transition from RMC to conventional concrete. Their publication states:

> the evolution of the internal combustion engine and the powerful mechanical equipment and plant that this development made possible, facilitated more efficient construction for major dams. Not only could a large dam be constructed in less time and at lower cost using crushed aggregates and sophisticated mixing plants, but the higher levels of quality and impermeability achieved, encouraged the design of more efficient structures.

The CIDB (2005:3) asserts:

> while these developments saw the application of masonry dams on large scale diminish after the first quarter of the 20th century in what is now the developed world, masonry dam construction has remained popular in the developing world, where low-cost labour is plentiful. In China, for example, very large gravity masonry structures (up to 95 m in height) were very popular until the advent of roller-compacted concrete in the early 1980s.

Prior to the 1960s, the use of what is now known as “conventional construction methods” was of little concern to developing countries. The IBRD (or World Bank) (IBRD 1986:1) states:

> with the exception of a few Asian countries, most developing countries, with the full support of the World Bank and other aid agencies, were bent on as rapid a mechanisation as was possible. This largely meant transferring the capital-intensive standards developed in the high-wage, capital-abundant countries of Europe, North America and Asia to the low-income, capital-scarce developing countries without questioning whether these technologies were appropriate.

According to McCutcheon (2003:20) the advent of the new “efficient” types of structures led to dams being built with fewer labourers and more machines.

> However, over the past century or so, conventional civil construction methods have become increasingly capital-intensive: the proportion of expenditure on fuel-powered equipment has increased substantially while that on labour has decreased.

King (1994:2) quoting Phillips (1992) gives reasons that masonry dams as a water storage medium were largely suspended in the early 20th century and replaced by the construction of more mechanised reinforced concrete arch dams and roller-compacted concrete dams:

- The large tax incentives allowed in respect of the purchase of new plant;
- Attempts to emulate the more mechanised approach of the construction industry in Europe and the USA; and
- The introduction of a wage determination process for the construction industry, which resulted in a substantial increase in the cost of labour.

A major procurement dispute in a World Bank member country in 1969 led to the bank announcing a programme of research on highway construction technologies, and later the study on the Substitution of Labour and Equipment in Civil Construction which was launched in March 1971 as a research and implementation project. One of the conclusions from this study by IBRD (World Bank) (1986:28) was that from

> the experience gained in comparing the costs of labor- with equipment-intensive construction showed that there is no clear, worldwide sweeping advantage of either. Each case must be considered on its own merits. There are many instances when labour-intensive construction methods will be financially more attractive than mechanised construction, particularly in countries where the prevailing agricultural daily wages are below empirically identified thresholds. In cases where there is a financial advantage for equipment-intensive operations, an analysis of economic costs will often show the convenience of employing labour-intensive methods. However, governments are inclined to choose construction methods on the basis of financial significance alone.

A new generation of RMC was developed in the 1980s. Rankine (2000) and the CIDB (2005) described its development as follows:

> In Zimbabwe, a resurgence in the use of rubble masonry concrete followed the unilateral declaration of independence by the Rhodesian Government in 1965, to reduce dependence on foreign currency, particularly for the consumption of liquid fuels and the replacement of machinery (Rankine 2000:2.5).

Rankine notes that engineers such as Mainwaring, Petzer, Hasluck, Wild, Robertson, Wooton, Stephens, dos Santos and Shelton

> have made many valuable practical contributions by way of empirical design, detailing and construction of RMC arch bridges and substantial dams; although by their own admission “on an ad hoc basis and without any code of practice”. They were motivated by a need to provide maximum infrastructure with very humble resources rather than by a philanthropic desire to “hand out” employment. As a result, their design and construction method, now known as the “Zimbabwe Method”, has become extremely cost effective and competitive (Rankine, 2000:2.5).

The CIDB (2005:4) states:

> New generation RMC was born out of a specific set of circumstances in Zimbabwe during a period of prolific dam construction in the mid-1980s.
>
> The particular circumstances in Zimbabwe are such that a general lack of availability of ready mix concrete, particularly in rural areas, compromises the competitiveness of all types of concrete on a small and medium scale. For many years, masonry dam construction was accordingly applied on small dams as a matter of necessity. Since 1985, however, masonry has been applied for larger dams at which the establishment of an aggregate crushing plant would be difficult to justify. For embankment dams, spillway sills and sidewalls have often been constructed in RMC, while arch dam walls and other structure types have been built up to heights of approximately 24 m. A general availability of suitable sites, in terms of topography, geology and materials, has now promoted the universal application of RMC technology on all but major dams throughout the country.

Rankine (2000) describes the methods of producing RMC in detail in his thesis entitled: "*Proposed design and construction guidelines for labour-intensively built rubble masonry concrete structures with particular reference to arch bridges*." Excerpts from Rankine's (2000) thesis are included for completeness:

> The Zimbabwean material differs from that used during the previous century in that the maximum boulder inclusion size has been limited to the mass a single man could handle, typically ranging between ~2 kg and as heavy as a man can comfortably lift (~40 kg). Accordingly, the volume proportion of mortar is significantly greater, typically about 45 to 55 %. First a thick layer of mortar (typically 150 mm) is spread horizontally into which the biggest stones are crudely packed as closely as practically possible without resorting to cutting or dressing them. Small stones or spalls are then pushed in between these boulders to reduce the interstitial volume of mortar. Once it becomes difficult to find new spaces for the spalls, a subsequent thick layer of mortar is spread on top of the previous masonry and the procedure of packing more boulders is repeated in horizontal lifts. Unless a deliberate attempt is made to the contrary, boulders tend to be placed with their longest axes and/or planar surfaces horizontal since this orientation is naturally most stable under gravity (p2.5).
>
> Unlike concrete, where the coarse aggregate particles become coated with a thin layer of mortar which tends to separate each particle from its adjacent neighbours, the boulder inclusions in RMC are usually forced into the mortar until they butt contiguously tight against one another (p2.5).

Rankine (2000:2.6) describes the favoured method of construction:

> [It] utilises the most experienced masons to build vertical outer leaves of masonry (typically 200 to 300 mm wide) with stiff mortar (typically 25 mm

> slump) to contain the inner core. Less experienced labourers then fill the inner core with higher slump mortar (typically 75 mm) and stone. Methods of compaction, to expel air, range from tamping the mortar with a crowbar, stick or trowel to kicking the rocks with their boots. Nevertheless, large air voids frequently remain beneath large boulders, against horizontal formwork and between tightly fitting rock surfaces.

Table 2.1, using combined data from CIDB (2005:7-10), shows some of the dams built in South Africa using RMC and includes an indication of quantity and person-days of labour.

## 2.3 Rubble masonry concrete dam construction technology

"*The Best Practice Guideline for Rubble Masonry Concrete Dam Construction Technology*" issued by the Construction Industry Development Board (CIDB 2005) in March 2005 summarises the critical aspects for construction of RMC dams. The guide covers the following topics:

- Material requirements
- Plant and equipment requirements
- Design considerations
- Construction technique
- Specialist literature.

This guideline, developed for South African conditions, is a comprehensive document for the client, contractor and designer to enable them to have a better understanding of RMC dam construction. The guideline also covers more advanced details including the behaviour of RMC dams with thermal expansivity.

In terms of *skills*, the CIDB (2005:33) states that

> Skilled masons are required for building the facing surfaces of the structure in advance of the core or hearting. Ideally these masons should have demonstrated their skills on a previous project … Their responsibilities will include the training of new masons and managing and directing their own support team who deliver material on the wall and who construct the hearting.

"Other staff" includes heavy manual labour, light manual labour, mortar batching and laboratory staff.

**Table 2.1: Rubble masonry concrete dam comparative information**

| Dam | Type | Maximum height (m) | RMC quantity $m^3$ | Employment (person-days of labour complete) | Year of completion |
|---|---|---|---|---|---|
| Bakubung | Multiple arch buttress | 14.5 | 2 650 | 9 000 | 1996 |
| Genadendal | Fill embankment with an RMC retaining wall and spillway sill | 9 | < 200 | | 1996 |
| Hogsback | Single arch with tongue walls and fill wrap-around sections | 11.5 | 1 750 | 50 labourers employed | 1999 |
| Keta | Earth embankment with RMC spillway | 10 | 1 230 | 1 500 | 2001 |
| Likalaneng | Single arch | | 1 700 | 6 800 | |
| Maritsane | Composite (RMC arch and earthfill embankment) | 18 | 5 600 | 12 000 | 1996 |
| Star | Single curvature arch | 11 | unknown | unknown | 2000 |
| Vrede/Tembalihle | Earth embankment / rockfill with RMC spillway | 18 | 800 | 500 | |
| Welgevonden | Single arch with fill embankment | 15 | 1 275 | 1 800 | 1999 |
| Source: CIDB (2005:7-10) | | | | | |

CIDB (2005:33) measures productivity rates by volume of masonry placed per day per worker.

> 'Worker' means all construction staff directly involved in the production and placement of masonry. Site management staff, technical staff and laboratory staff are excluded. Their costs should be included under Preliminary and General items. All workers employed in the sourcing and delivery of construction materials to the site of works, are also excluded. Their costs should be reflected in the material procurement costs which, in turn, will later be incorporated in the masonry cost (CIDB, 2005:33-34).

CIDB (2005:34) continues:

> productivity rates vary widely, from as little as 0.3 $m^3$ per person per day to as much as 5 $m^3$ per person per day. The latter productivity rate can only be achieved if the manual transportation of masonry rock and mortar onto the wall is replaced with mechanical delivery systems. The cost of mechanical delivery systems should then be separately calculated and converted into a cost per cubic meter of masonry placed. If the entire process from rock stockpile and mortar batching plant to construction of masonry walls are done with manual labour, then typical productivity varies between 0.5 $m^3$ per person per day to 1.0 $m^3$ per person per day.

CIDB (2005:33) lists the following factors as influencing productivity:

- The skills, attitude and experience of the work force
- Remuneration incentives
- Leadership on the site
- Working conditions (both social and physical)
- Weather conditions
- Access and working space (better access and lots of working space increase productivity)
- Total volume (the greater the volume, generally the higher the productivity due to the relatively short learning curve in relation to the overall duration of the project)
- Availability of construction materials (a bottleneck in material deliveries can severely hamper productivity and can cause the workforce to become demoralised)
- Construction methods and material delivery onto the wall (the more mechanised, generally the higher the productivity rates, but the additional costs of mechanisation must be weighed up).

## 2.4 The Department of Water Affairs: Construction as an in-house public sector contractor

The Department of Water Affairs has an in-house contractor and, due to the large role they play in the Dam Safety Rehabilitation Programme, it was decided to include a discussion of their in-house contractor in the literature review. Most of the dam safety rehabilitation work is currently done by the in-house contractor. In this research project, Molepo Dam, Chuniespoort Dam and Klein Maricopoort Dam were all rehabilitated by the in-house contractor, DWA: Construction, being the main contractor.

Mulder (2011:265) wrote a paper entitled: "*Rehabilitation of dams using in-house contractors: Lessons learnt from the contractor's perspective: A case study from South Africa*." Mulder uses four specific projects to describe the advantages of having an in-house contractor. At **Thabina Dam** (p.267):

> the work was carried out with no full-time engineer on site due to the fact that the in-house contractor had a competent and trusted site agent. Because the in-house contractor was utilised to carry out the work, it was possible to respond quickly to repair the flood damage, including the reconnection of a pipeline which supplies water to the surrounding villages.
>
> In 2000, the eastern and northern parts of South Africa were hit by tropical storms, which caused widespread flooding...

which included damage to **Thapane Dam** (p.267).

> Engineers from the Dam Safety office [actually, subdirectorate] decided that temporary repairs were urgent to prevent failure of the dam and consequently the in-house contractor (p.267)

was called upon urgently to mobilise to site.

> Two weeks after initial damage, 500 mm of soil was placed on top of the crest, which prevented the wall from (p.267)

overtopping "during a second round of flooding in 2000."

> Because work at the dam was done on an actual cost basis, this meant that the final cost of the project was kept to a minimum (p.267).

According to Mulder (2011:268), for **Kammanassie Dam**, the budget for the rehabilitation work was spread over a number of financial years. The result was that

> any contractor appointed to do the work, needed to be able to accelerate and decelerate at short notice, and perhaps even stop work. This should be done by keeping costs, including claims, as low as possible (p.268)

The work was executed in various phases:

> Only actual costs have been claimed for work done, which meant that, despite the stop-start approach to the project, and uncertainties regarding funding, the refurbishment of the project could be completed within budget and with no disputes regarding costs (p.268).

Mulder (2011) asserts that at **Pongolapoort Dam** the extent of the rehabilitation is unknown but, as the design is being done in phases, the scope of construction work will eventually become known. The researcher believes that, in this situation, the use of an in-house contractor executing work in phases may be to the advantage of the client.

Kroon (2013), Chief Engineer at DWA: Project Implementation, mentioned the following concerns from a client's perspective of appointing DWA: Construction as a contractor:

- There is no open tender which makes it impossible to sell to water users who must pay the water tariff,
- DWA: Construction has few fully qualified staff left,
- State procurement procedures make it impossible to construct cost effectively,
- There is no recourse for the client if the project is late or should costs overrun,
- Programming skills are thinly spread at the Contractor, and
- Many experienced foremen have retired.

Mulder (2011) made a few recommendations that could assist DWA: Construction with streamlining their work. Firstly, conditions of service should be separate from those of most employees in the Public Service. Employees should be able to be appointed on short-term contracts as they are project bound. Employees should also receive benefits like housing, transport and various allowances. According to Mulder (2011:269):

> The provisions of this separate set of conditions of service should also allow for different working hours than the rest of the civil service, easier transfer of personnel, as well as shorter appointment and termination procedures.

Secondly, Mulder (2011:269) notes:

> The in-house contractor is responsible for a significant number of transactions per day. Everything from consumables through to construction materials and services have to be procured within the procurement delegations of the DWA. Construction is by nature prone to many changes. That is partially due to a lack of complete information at the beginning of a project. [Private] contractors can normally deal reasonably well with sudden changes, since all major construction contracts, such as FIDIC and NEC3 deal with issues such as payment for extra work and extension of time. If provision is not made to accommodate unplanned changes to work, which necessitates procurement outside the normal procurement provisions of government, an in-house contractor will be inefficient as part of a public entity. One way to solve this problem is to delegate the authority to approve procurement, outside normal procedures, to individuals involved in the construction process. Typically a limit should be placed on the amount that a Contracts Manager, Director or Chief Director can approve.

In conclusion, Mulder (2011:269) opines:

> the in-house contractor should not be seen as a solution under all circumstances, but rather as a contractor to be used under certain conditions. Under conditions where there is adequate capacity in the market, and where most or all unknowns can be clarified prior to the start of construction, work can be outsourced to private sector contractors. Some mechanism should exist to ensure that the efficiency and rates of the in-house contractor are measured against those of private contractors, but at the same time the in-house contractor should not necessarily compete with the private sector, since the justification for having an in-house contractor is not to simply create another contractor. Rather this contractor should be utilised in specific cases.

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Topics covered in the literature review include the definition and objectives of labour-intensive construction; the history of RMC, the emergence of conventional concrete and the rebirth of RMC; RMC dam construction technology, and the Department of Water Affairs: Construction as an in-house contractor. The next chapter contains the research methodology and findings.

# 3 Research methodology and findings

Following the literature review in Chapter 2, the research methodology is discussed in this chapter and the findings of the research are presented.

## 3.1 Choice of dams and methodology

The dams studied in this research (Figure 1.1) were rehabilitated as part of the Dam Safety Rehabilitation Programme which was launched in 2005. Molepo Dam, Chuniespoort Dam, Mashashane Dam and Albert Falls Dam were earmarked for labour-intensive construction after the preliminary design stages. Molepo Dam, Chuniespoort and Mashashane Dam are situated in Limpopo Province and have been rehabilitated. They feature RMC in some components. Klein Maricopoort is in North-West Province and features a conventional construction method by means of placing mass concrete and is included only for comparison purposes. Lastly, Albert Falls Dam is in KwaZulu–Natal and features a brick parapet wall which was constructed labour-intensively.

To undertake this research, the researcher made use of monthly progress reports, spreadsheets compiled by site agents and information from contractors to compile the number of labour opportunities created. Detailed costing sheets with actual costs were used to examine the costs at DWA: Construction sites. The man-hour and cost data for Mashashane Dam were supplied by Stefanutti Stocks and were not verified. The cost information for Albert Falls Dam was obtained from payment certificates.

The abovementioned five dams were researched as case studies which are documented in Sections 3.2 to 3.6.

## 3.2 Molepo Dam

Molepo Dam was originally completed in 1987 by the former Lebowa government (Shaw, 2006a). Water from the dam is pumped to a purification works, located on the upper right flank and used for domestic consumption. Shaw (2006a:2) asserts that "Molepo Dam became the responsibility of the National Department of Water Affairs (and Forestry) after 1994."

The main dam statistics, obtained from Shaw (2006a:3) and Cameron-Ellis (2013) are summarised in Table 3.1, from which it can be seen that the old spillway capacity before rehabilitation was much smaller than the Safety Evaluation Flood that the spillway is required to pass safely.

**Table 3.1: Molepo Dam statistics**

| | |
|---|---|
| Height | 16 m |
| Category | II |
| River | Mphogodima River |
| Catchment area | 248 $km^2$ |
| FSL[1] | RL 1118.6 m |
| NOC[2] | RL 1121 m |
| Gross storage | 4.1 x $10^6$ $m^3$ |
| RDF[3] (Q100) | 420 $m^3/s$ |
| SEF (RMF)[4] | 1 575 $m^3/s$ |
| Spillway capacity (existing) | 290 $m^3/s$ |
| Spillway capacity (new) | 1 645 $m^3/s$ |
| 1 Full supply level 2 Non-overspill crest 3 Recommended design flood<br>4 Safety evaluation flood (regional maximum flood) | |
| Source: Shaw (2006a:3) and Cameron-Ellis (2013) | |

The Molepo Dam rehabilitation design report (Shaw, 2006a:4) states

> the concept design for the provision of increased spillway capacity at Molepo Dam envisaged the development of a new spillway channel down the left flank, where competent rock is evident. Suitable early alignments, however, indicated

> the need for very significant quantities of rock excavation, exceeding 200 000 $m^3$. Whilst it was possible to reduce these quantities to a certain extent through optimisation of the alignment, an alternative spillway arrangement was conceived, effectively involving the replacement of the far left section of the dam embankment with an RMC multiple arch buttress structure, which could serve as a spillway. This solution not only demonstrated a cost saving over the original design concepts, but also allowed the inclusion of a new outlet works within the RMC and allowed the development of the necessary spillway capacity without any real raising of the existing dam embankment.

Shaw (2006a) noted the proposed rehabilitation included:

- The construction of a new RMC spillway structure on the left flank, in combination with a certain amount of rock excavation by blasting to create adequate approach capacity, suitably orientated footings for the dam structure and an initial discharge channel that will route spillage away from the embankment toe (p.4).
- Rehabilitating the remaining section of the existing embankment through reshaping, recompaction of the downstream face fill material, the provision of upstream face rip rap and downstream face gravel erosion protection, toe berms and toe drains (p4.).
- Creating a new outlet works, with a river release facility in the new RMC structure (p.4).
- Grouting beneath the RMC structure, in the location where the new wall meets the old embankment and in the general area on the left flank where seepage is currently evident (p.4).

Shaw (2006a:5) further states:

> it should be borne in mind that, within the applicable time frame, exhaustive investigations for the proposed rehabilitation work were not possible and that a certain amount of design development and optimisation would consequently be unavoidable during the early stages of construction. For example, before the optimal/final RMC wall arrangements and orientations can be established, the overburden materials in the affected area would need to be excavated and the rock mapped.

The decision not to do a full geological exploration proved to be the wrong decision based on the comments by Stassen (2012) (Section 3.2.1).

### 3.2.1 Factors that influenced productivity and cost on site

The researcher had a meeting with the site agent (Stassen, 2012) of Molepo Dam on 20 August 2012 and discussed the challenges of the construction of

Molepo Dam with specific reference to the RMC sections. From the discussions with Stassen and others the following unique site-specific conditions emerged that influenced productivity and costs:

- Materials were a problem as only 30 to 40 % of the masonry rock material obtained from site could eventually be used for the structure. Blasting had to take place in order to obtain suitable material which was an expensive exercise.
- At least six months' training was done to get the locals ready for production. According to Stassen (2012) he was fortunate that some locals were well skilled in building houses with masonry rock.
- Initially it was planned to use conveyor belts to transport material on site. The foundations were estimated to be 9 m deep, but actual conditions revealed foundations approximately 18 m deep. Due to technical difficulties relating to the much deeper foundations, two overhead cranes were rented at a cost of ZAR3 000 to ZAR4 000 per day which increased the overall costs considerably. The extensive use of mechanical equipment to transport the material would increase the productivity on site, but also increase the cost of the RMC structure.
- The planned placement rate of RMC was 1 500 $m^3$/month. Actual figures resulted in a placement rate of 756 $m^3$/month, approximately half of the estimated placement rate. This average includes the December breaks where no RMC placement was possible. There were, however, four months that exceeded the planned placement rate which had rates of 2 243 $m^3$/month, 2 211 $m^3$/month, 1 810 $m^3$/month and 1 611 $m^3$/ month. It should be noted that this was the first RMC structure undertaken by DWA: Construction and a big "learning curve". The site agent was also new in his position at the time.
- In terms of RMC volume placed (more than 20 000 $m^3$), the Molepo Dam rehabilitation project represents by far the largest placement of RMC studied in this research project. Larger volume projects have the advantage of having greater productivity due to the relatively shorter learning curve.
- Access became an issue as the project moved into the advanced stages due to limited working space and occupational health and safety issues as workers had to be harnessed as required by law.

These challenging working conditions would have a negative impact on the productivity on site.

### 3.2.2 Molepo Dam labour opportunities and cost

The following information regarding costs and placement was obtained from the monthly reports and cost report:

| | |
|---|---|
| Total cost of rehabilitation: | ZAR140 m |
| RMC spillway rehabilitation cost: | ZAR39.66 m |
| RMC quantity for spillway: | 20 413 $m^3$ |
| Actual unit price: | ZAR1 943 /$m^3$ |
| Peak placement rate: | 2 243 $m^3$/month |
| Average placement rate: | 756 $m^3$/month |
| Low placement rate: | 132 $m^3$/month |

Records of the workforce were only recorded between April 2008 and August 2009. From these data the following can be derived:

| | |
|---|---|
| **Average number of workers employed per month (including overhead staff)** | 129 |
| **Average number of locals employed per month** | 110 |
| **Average number of RMC employees per month** | 3 supervisors<br>+ 25 bricklayers<br>+ 64 labourers<br>**= 92 persons** |
| **Total productive days** | 540 days – 53 rain days claimed = **487 productive days** |
| **Number of hours worked per day** | 9 hours |
| **Total number of man-hours worked** | 487x9x92 = 403 236 man-hours |

| | |
|---|---|
| **on the project** | |
| **Total volume of RMC placed** | 20 413 $m^3$ |
| **Labour opportunities in man-hours/$m^3$** | 403 236 man-hours/20 413 $m^3$<br>= **19.75 man-hours/$m^3$** |

The design report (Shaw, 2006a) reflected the RMC in the bill of quantities as being 8 000$m^3$ at R600/$m^3$, which is considerably less than the 20 413 $m^3$ actually placed at a cost of R1 943/$m^3$.

### 3.2.3 Molepo Dam productivity

"Productivity" is calculated using the CIDB (2005:33) definition of volume of masonry placed per day per worker. "Worker" means all construction staff directly involved in the production and placement of masonry. Site management staff, technical staff and laboratory staff are excluded. All workers employed in the sourcing and delivery of construction materials to the site of works are excluded.

| | |
|---|---|
| **Labour** | 25 bricklayers<br>+ 64 labourers<br>**= 89 persons** |
| **Productive days** | 540 days – 53 rain days claimed =<br>**487 productive days** |
| **Volume RMC placed** | 20 413 $m^3$ |
| **Productivity** | 20 413 $m^3$ / 89 persons / 487 days<br>= **0.47 $m^3$/person/day** |

Figures 3.1 to 3.6 show Molepo Dam spillway in various stages of construction and at completion.



**Figure 3.1: Molepo Dam spillway during construction (1)**



**Figure 3.2: Molepo Dam spillway during construction (2)**



**Figure 3.3: Molepo Dam spillway during construction (3)**



**Figure 3.4: Molepo Dam spillway ogee profile during construction**



**Figure 3.5:** **Molepo rubble masonry concrete pump house during construction**




**Figure 3.6:** **Molepo Dam completed**

## 3.3 Chuniespoort Dam

Cameron-Ellis (2008:2) asserts:

> Chuniespoort Dam was originally constructed for the purposes of irrigation and municipal water supply and the dam currently serves domestic users in thirteen villages in the Chuene-Maja area, via the Maratapelo water purification works. In addition, the impoundment is of importance for a recreational resort and a crocodile farm, which operates on the perimeter of the dam.
>
> Originally constructed by the Bantu Administration and Development Department in 1951. Chuniespoort Dam became the responsibility of the Department of Water Affairs [formerly Water Affairs and Forestry] after 1994 (Cameron-Ellis, 2008:2).

The following dam safety deficiencies were observed by Cameron-Ellis (2008) during the inception stage at Chuniespoort Dam which made the Department of Water Affairs decide to continue with rehabilitation at the dam:

- The existing spillway capacity at the dam is inadequate and must be enlarged (p.2.);
- Ongoing erosion problems in the steep spillway channel require attention (p.2);
- The feasibility of the current spillway arrangement to accommodate the required floods must be carefully considered (p.2);
- Ongoing erosion of the downstream face of the embankment, the embankment crest and some areas on the upstream face is a significant problem that requires a definitive solution (p.2);
- The upstream face rip-rap slope protection is rather thin and inadequate (p.2);
- The inlet/outlet works are not realistically usable in their current state and require attention, upgrading and probably modification (p.2).

According to Cameron-Ellis (2008:3), the statistics for Chuniespoort Dam are as shown in Table 3.2.

**Table 3.2: Chuniespoort Dam statistics**

| | |
|---|---|
| Height | 15 m |
| Category | II |
| River | Chunies River |
| Catchment area | 180 $km^2$ |
| FSL[1] | RL 1 145.13 m |
| NOC[2] (new) | RL 1 150.45 m |
| Gross storage | 2.47 x $10^6$ $m^3$ |
| RDF[3] (Q100) | 316 $m^3/s$ |
| SEF (RMF)[4] | 1 342 $m^3/s$ |
| Spillway capacity (existing) | 280 $m^3/s$ |
| Spillway capacity (new) | 1 214 $m^3/s$ |
| 1 Full supply level 2 Non-overspill crest 3 Recommended design flood<br>4 Safety evaluation flood (regional maximum flood) | |
| Source: Cameron-Ellis (2008:3) and Cameron-Ellis (2013) | |

Three different options were proposed in Cameron-Ellis' (2008) Chuniespoort Dam Conclusive Design Report. All three alternatives included RMC retaining structures on the right-hand side spillway and an emergency spillway on the left-hand side of the dam. The emergency spillway on the left-hand side was eventually rejected by Management of the then Civil Design of the Department of Water Affairs as they felt that the floods calculated are too big and the costs of the rehabilitation is exorbitantly high.

The design was later modified and construction started in September 2010.

### 3.3.1 Factors that influenced productivity and cost on site

The following factors influenced productivity and cost on site:

- Rock was acquired free of charge from the Lonmin Lebowakgomo mine, 27 km away, on condition that the cost of haulage from the site is carried by the Department and that the staff who will access the mine be inducted in terms of the mine's safety programme.

- The core RMC team was moved from Molepo Dam to Chuniespoort dam and was able to assist with training unskilled labour from the area.
- Several delays were encountered on the site, procurement difficulties being the largest cause of delays. Diesel shortages were experienced during August 2011 and cement shortages were experienced during November 2011. These delays are not due to poor planning from the site agent's time but rather the DWA: Head Office not having term contract suppliers in place. Normal adverse weather delays like rainfall were also experienced on site during this period.
- The spillway structure was straightforward as opposed to the more complex spillway structure at Molepo Dam. Similarly, the parapet wall design was straightforward and relatively easy to construct.
- The site agent put an incentive scheme in place for the construction of the parapet wall and gave clear targets for incentive rewards.

### 3.3.2 **Cost of spillway and parapet wall**

The overall RMC cost for the Chuniespoort Dam spillway and parapet wall is:

| | **Volume** | **Cost** |
|---|---|---|
| **Spillway** | 8 480 $m^3$ | ZAR 15 586 100 |
| **Parapet wall** | 1 060 $m^3$ | ZAR 5 431 700 |
| **Total** | 9 540 $m^3$ | ZAR 21 017 800 |
| **Average cost/$m^3$** | | **ZAR2 203/$m^3$** |

### 3.3.3 Chuniespoort Dam rubble masonry concrete spillway

The discussion on the Chuniespoort Dam RMC spillway is divided into two sub-sections – the labour opportunities and the productivity.

#### *3.3.3.1 Chuniespoort Dam spillway labour opportunities*

The spillway was constructed in RMC and construction started on 13 September 2010 and was completed end of August 2012 except for some minor work that continued afterwards.

According to the site agent, Felix Mothiba (2012), the following persons were employed on the site:

| | |
|---|---|
| **Labour** | 14 Bricklayers<br>+ 42 labourers<br>+ 16 labourers for selection of material<br>+ 8 labourers in batching plant<br>= **80 persons**<br>This figure excludes the two surveyors who set out the site |
| **Total productive days** | 422 productive days |
| **Number of hours worked per day** | 9 hours |
| **Total number of man-hours worked on the project** | 422 x 9 x 80 = 303 840 man-hours |
| **Total volume of RMC placed** | 8 480 $m^3$ |
| **Labour opportunities in man-hours/$m^3$** | 303 840 man-hours / 8 480 $m^3$<br>= **36 man-hours/$m^3$** |

Due to the relatively small contribution from the surveyors, their contribution in terms of man-hours is ignored for the purposes of calculating the man-hours on this project. This brings the total staff complement at the RMC spillway section to 80 employees.

The researcher obtained the placement rate of RMC from the site agent. By subtracting rain days, holidays and delays due to shortages of material and fuel, the total productive days for construction of the spillway was calculated at 422 days.

The construction of the RMC spillway had no incentive scheme for early completion of tasks.

#### *3.3.3.2 Chuniespoort Dam spillway productivity*

The parameters for measuring productivity on the Chuniespoort Dam spillway are:

| | |
|---|---|
| **Labour** | 14 Bricklayers<br>+ 42 labourers<br>= **56 persons**<br><br>This figure excludes the two surveyors who set out the site |
| **Productive days** | 422 productive days |
| **Volume RMC placed** | 8 480 $m^3$ |
| **Productivity** | 8 480 $m^3$ / 56 persons / 422 days<br>= **0.36 $m^{3/}$person/day** |

### 3.3.4 Chuniespoort Dam rubble masonry concrete parapet wall

The Chuniespoort Dam RMC parapet wall is discussed in two sub-sections – the labour opportunities and the productivity. A sketch of the dimensions of the Chuniespoort Dam RMC parapet wall is presented in Figure 3.7.

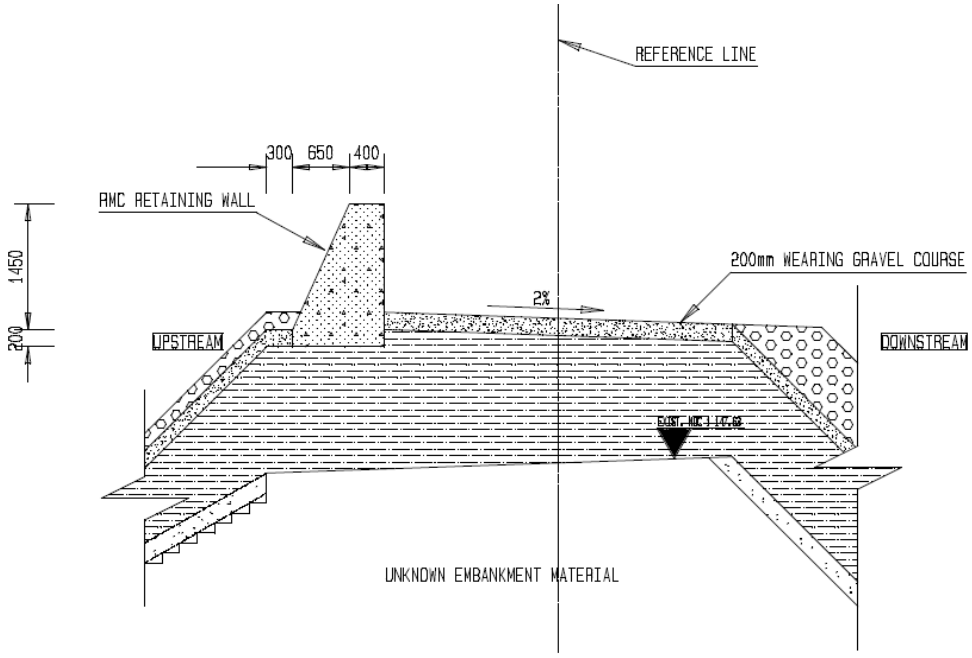


**Figure 3.7: Chuniespoort Dam – sketch of parapet wall**

### *3.3.4.1 Chuniespoort parapet wall labour opportunities*

The parapet wall was designed using RMC. However, prior to construction of the parapet wall the client (represented by the researcher) was approached by the contractor to use conventional construction methods in order to speed construction up. The request was turned down by the researcher in his capacity as the client.

Construction to the RMC parapet wall started on 11 May 2012 and finished 80 working days later on 08 August 2012. The quantity of RMC placed was 1 060 $m^3$ over a length of 680 m. The dimensions of the parapet wall are shown in Figure 3.7.

The staff complement for the work comprised:

| | |
|---|---|
| **Labour** | 14 Bricklayers<br>+ 28 labourers<br>+ 2 supervisors<br>= **44 persons** |
| **Total productive days** | 80 productive days |

| | |
|---|---|
| **Number of hours worked per day** | 9 hours |
| **Total number of man-hours worked on the project** | 44 x 9 x 80 = 31 680 man-hours |
| **Total volume of RMC placed** | 1 060 m3 |
| **Labour opportunities in man-hours/$m^3$** | 31 680 man-hours/1 060 m3 = **30 man-hours/$m^3$** |

Two gangs – consisting of a supervisor, seven bricklayers and 14 labourers – worked on the parapet wall.

The method used to construct the RMC wall was two-part. First the bricklayers constructed the outer shell. Thereafter, the labourers filled the shell with internal 'rubble' mass.

The site agent used an incentive scheme to encourage workers to perform optimally on the RMC parapet wall. This arrangement proved successful and countered the usual norm on construction sites to have increasingly lower productivity towards the end of a project in order to extend the employment period for as long as possible.

Using the assumption of a 9-hour workday, the total man-hours spent on the parapet wall equates to 9 hours x 80 days = 720 man-hours per labourer.

The project utilised 44 labourers so the total man-hours = 720 x 44 = 31 680 man-hours for the construction of the parapet wall.

The man-hours per $m^3$ then equates to 31 680 man-hours / 1 060 $m^3$ = **30 man-hours/$m^3$**.

It should be noted that due to the nature and dimensions of a parapet wall, very little internal rubble mass is "dumped". It should also be borne in mind that the batching plant labourers and labourers collecting the material are excluded from the above figure as the two sub-projects ran concurrently and these employees were mainly employed for the spillway section.

### *3.3.4.2 Chuniespoort Dam parapet wall productivity*

The parameters for measuring productivity on the Chuniespoort Dam parapet wall are:

| | |
|---|---|
| **Labour** | 14 Bricklayers<br>+ 28 labourers<br>= **42 persons** |
| **Productive days** | 80 productive days |
| **Volume RMC placed** | 1 060 $m^3$ |
| **Productivity** | 1 060 $m^3$ / 42 persons / 80 days<br>= **0.32 $m^3$/person/day** |

## Expenditure and man-hours expressed per $m^2$

For comparison purposes, the cost and man-hours are also expressed per $m^2$:

| | |
|---|---|
| **Height of parapet wall** | 1.65 m |
| **Length of parapet wall** | 680 m |
| **Area of parapet wall** | 1 122 $m^2$ |

This equates to a cost of

| | |
|---|---|
| **Cost per $m^2$** | R5 431 700 / 1 122 $m^2$<br>= **R4 841 per $m^2$** |
| **Labour opportunities in man-hours/$m^2$** | 31 680 man-hours / 1 122 $m^2$<br>= **28.24 man-hours/$m^2$** |

Figures 3.8 and 3.9 show the Chuniespoort Dam spillway construction. Figure 3.10 shows the Chuniespoort Dam parapet wall, Figure 3.11 shows the Chuniespoort Dam appurtenant structures and Figure 3.12 shows a Chuniespoort Dam stormwater canal. The completed Chuniespoort Dam RMC spillway is shown in Figure 3.13.



**Figure 3.8:** **Chuniespoort Dam spillway construction (1)**



**Figure 3.9:** **Chuniespoort Dam spillway construction (2)**



**Figure 3.10: Chuniespoort Dam parapet wall**




**Figure 3.11: Chuniespoort Dam appurtenant structures**



**Figure 3.12:** **Chuniespoort Dam stormwater canal**



**Figure 3.13:** **Chuniespoort Dam completed rubble masonry concrete spillway**

## 3.4 Mashashane Dam

According to the Mashashane rehabilitation preliminary design report (Shaw, 2006b):

> Mashashane Dam was apparently constructed as a primary source to serve local domestic users with potable water … In the recent past, a pump station has been constructed at the toe of the dam wall and the water is pumped to a purification works for local domestic users (p.2).
>
> Mashashane Dam comprises an earthfill embankment of approximately 520 m in length and 16 m high, flanked on the left side by an uncontrolled by-wash spillway. The embankment comprises homogeneous fill of organic origin and appears to have been built on top of a smaller, pre-existing wall. The original wall is clearly evident as a berm at the toe of the existing embankment and an old spillway channel on the left flank can be determined at the level of the berm (p.3).

According to Shaw (2006b:3) and Beukes (2013), the statistics for Mashashane Dam (Table 3.3) are:

**Table 3.3: Mashashane Dam statistics**

| | |
|---|---|
| Height | 16 m |
| Category | II |
| River | Hout River |
| Catchment area | 11.5 $km^2$ |
| FSL[1] | RL 1403.62 m |
| NOC[2] | RL 1405 m |
| Gross storage | 892 x $10^3$ $m^3$ |
| RDF[3] (Q100) | 108 $m^3/s$ |
| SEF (RMF)[4] | 339 $m^3/s$ |
| Spillway capacity (existing) | 290 $m^3/s$ |
| Spillway capacity (new) | 390 $m^3/s$ |
| 1 Full supply level 2 Non-overspill crest 3 Recommended design flood<br>4 Safety evaluation flood (regional maximum flood) | |
| Source: Shaw (2006b:3) and Beukes (2013) | |

The problems identified at the dam (Shaw, 2006b:3) are summarised below:

- The optimal solution for providing the necessary larger spillway capacity (p.3).
- Optimal dam rehabilitation within the identified constraints (p.3).
- The upstream face protection to mitigate erosion problem (p.3).
- Mitigate termite infestation (p.3).
- To prevent the grass and vegetation growth and associated cattle grazing on the downstream face of the embankment (p.3).
- Downstream face protection to prevent erosion (p.3).

### 3.4.1 Factors that influenced productivity and cost on site

The following factors influenced the productivity and cost on site:

- The batching plant is right next to the RMC spillway and will consequently boost productivity.
- The spillway design is straight forward and relatively easy to construct with ample access.
- The foundation was mostly constructed by dumping RMC into the excavated area with a backhoe. This would have increased productivity.
- A large amount of suitable material was left on site by a previous contractor. Material was also obtained from a mine in the nearby vicinity with short hauling distance. According to Grimsehl (2013), the material was also used for the rip rap and may have been costed against the rip rap.

### 3.4.2 Mashashane Dam labour opportunities

The spillway structure was built from RMC material. The following information was supplied by the site agent of Stefanutti Stocks (Lawana, 2012):

| | |
|---|---|
| Total cost of RMC structure | ZAR1 839 500 |
| Quantity of whole wall and base | 1 790 $m^3$ |
| Rate per $m^3$ | ZAR1 048 |

Total man-hours were:

| | |
|---|---|
| **Labour** | 5 Bricklayers<br>+ 6 labourers mixing concrete<br>+ 6 labourers collecting rock<br>+ 14 labourers placing rock<br>+ 1 supervisors<br>= 34 persons |
| **Total productive days** | 130 productive days |
| **Total number of man-hours (m-hrs) worked on the project** | Bricklayers: 5 805 m-hrs<br>Labourers mixing concrete: 6 966 m-hrs<br>Labourers collecting rock: 5 940 m-hrs<br>Labourers placing rock: 16 430 m-hrs<br>Supervisor: 1161 m-hrs<br>= **36 302 man-hours** |
| **Total volume of RMC placed** | 1 790 m3 |
| **Labour opportunities in man-hours/$m^3$** | 36 302 man-hours/1 790 $m^3$<br>= **20.3 man-hours/$m^3$** |

### 3.4.3 Mashashane Dam productivity

The productivity on the Mashashane project was:

| | |
|---|---|
| **Labour** | 14 labourers<br>+ 5 builders (skilled masons)<br>**= 19 persons** |
| **Duration of project** | 130 productive days |
| **Volume RMC placed** | 1 790 $m^3$ |
| **Productivity** | 1790 $m^3$/19 persons/130 days<br>= **0.72 $m^3$/person/day** |

Figures 3.14 to 3.17 show the Mashashane Dam spillway during construction and after completion.



**Figure 3.14: Mashashane Dam spillway during construction (1)**



**Figure 3.15: Mashashane Dam spillway during construction (2)**



**Figure 3.16: Mashashane Dam completed spillway**



**Figure 3.17: Mashashane Dam completed**

## 3.5 Klein Maricopoort Dam

Klein Maricopoort Dam is situated approximately 7 km east of Zeerust on the Klein Marico River (BKS 2012). The dam was constructed in 1935 by the Department of Water Affairs and raised in 1965. It is a Category III dam and is mainly used for irrigation.

> The original structure is a zoned embankment dam encompassing an earthfill embankment with a central thin concrete core wall, a semi-pervious to pervious upstream region and a thin rockfill downstream region with a side channel (trough) ogee spillway on the right flank. The outlet components consisted of an inlet tower with three multi-level intakes that discharged water into an irrigation canal downstream of the embankment wall (BKS 2012:2).

The main dam statistics, as obtained from BKS (2012:3), are summarised in Table 3.4. From the table it can be seen that the spillway capacity before rehabilitation was much smaller than the Safety Evaluation Flood.

**Table 3.4: Klein Maricopoort Dam statistics**

| | |
|---|---|
| Height | 27 m |
| Category | III |
| River | Klein Marico River |
| Catchment area | 1 180 $km^2$ |
| FSL[1] | RL 1160.87 m |
| NOC[2] | RL 1164.63 m |
| Gross storage | 7.07 x $10^6$ $m^3$ |
| RDF[3] (Q200) | 720 $m^3/s$ |
| SEF (RMF)[4] | 2190 $m^3/s$ |
| Spillway capacity (existing) | 1 028 $m^3/s$ |
| Spillway capacity (new) | 2 190 $m^3/s$ |
| 1 Full supply level 2 Non-overspill crest 3 Recommended design flood<br>4 Safety evaluation flood (regional maximum flood) | |
| Source: BKS (2012:3) | |

The main issues at the dam were (BKS, 2012:4):

- Inadequate flood handling capacity. (Previous studies found that the original spillway capacity was limited to a flood in the range of 815 to 1 028 $m^3/s$, which is inadequate for a SEF of 2 190 $m^3/s$).
- The embankment did not contain the normal drains or had settled and the crest was uneven.
- The cable anchors in the spillway gravity section fillers, which anchored the structure to the foundations, were possibly non-functional.
- The bottom outlet leaked into the embankment, which posed the risk of piping failure of the embankment.

The following information was obtained from the monthly reports and cost report:

- Total cost of project: ZAR56 m.
- Conventional concrete quantity for spillway and weir: 10 465 $m^3$.
- Actual unit price of placing concrete: ZAR2 390/$m^3$. This price includes shuttering and reinforcement but, for comparative purposes, excludes grouting and excavations.

Construction started in September 2009 and ended in November 2011. The workforce per month peaked in August 2010 with ten permanent employees and 94 project-based local employees.

For this project the following assumptions were made in order to calculate the man-hours spent on the concrete placement of the spillway:

- Monthly reports were used to obtain the quantities of concrete placed for the spillway and weir.
- Employees work 9 hours per day and actual work days were taken from the calendar.
- The average monthly rain days and average monthly rain was used to calculate the number of days lost due to actual rain.
- Only productive days were used which means normal days minus days where work could not be done due to labour unrest, procurement problems, inclement weather conditions and days lost due to the spillway spilling while working.

- The dates used for evaluation was from the first placement of concrete in November 2009 until November 2011 when concrete placement became negligibly small.
- A percentage was used to indicate the percentage of workers used on the spillway section. For the most part it was assumed that 85 % of the workforce was active on the concrete spillway section as this was the main activity at the dam.

The man-hours were calculated by taking the productive days and multiplying it with the percentage active workers on the spillway, then multiplying it by the number of workers for that month and lastly with 9 hours per day so, for August 2010, there would have been 21 x 0.85 x 104 x 9 = 16 707 man-hours.

The overall labour opportunities in man-hours/$m^3$ are:

| | |
|---|---|
| **Total number of man-hours worked on the project** | 232 722 man-hours |
| **Total volume of conventional concrete placed** | 10 465 $m^3$ |
| **Labour opportunities in man-hours/$m^3$** | 232 722 man-hours/10 465 $m^3$ = **22.24 man-hours/$m^3$** |

Figure 3.18 shows the Klein Maricopoort Dam new concrete spillway.



Source: BKS (2012)

**Figure 3.18: Klein Maricopoort Dam new concrete spillway**

## 3.6 Albert Falls Dam

Albert Falls Dam is a composite earthfill/concrete structure in KwaZulu-Natal and is situated roughly 20 km north of Pietermaritzburg on the Umgeni River (Badenhorst and van Wyk, 2008). The dam had an insufficient spillway capacity prior to the raising that took place in 2010. The insufficient spillway capacity was overcome by constructing a parapet wall on the upstream side of the non-overspill crest. Three options were investigated to construct the parapet wall and the brick wall was not only the least expensive option, but was also chosen to promote labour-intensive construction. Figure 3.19 illustrates the dimensions of the Albert Falls Dam parapet wall.

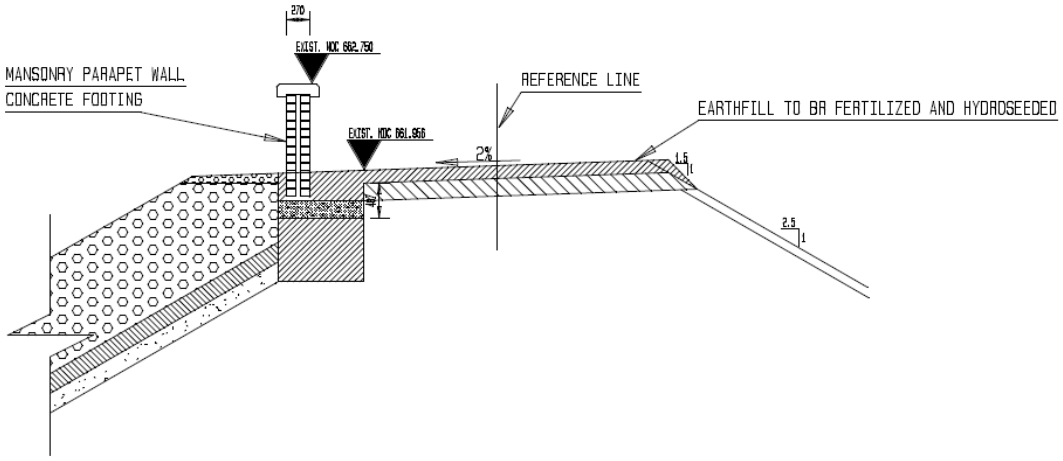


**Figure 3.19: Albert Falls Dam – sketch of parapet wall**

The main dam statistics are summarised in Table 3.5 as obtained from Badenhorst and van Wyk (2008). From the table it can be seen that the spillway capacity before rehabilitation was much smaller than the Safety Evaluation Flood.

**Table 3.5: Albert Falls Dam statistics**

| | |
|---|---|
| Height | 35.75 m |
| Category | III |
| River | Umgeni River |
| Catchment area | 1 653 $km^2$ |
| FSL[1] | RL 655.9 m |
| NOC[2] | RL 662.75 m (previous RL662.0 m) |
| Gross storage | 287 x $10^6$ $m^3$ |
| RDF[3] (Q200) | 1 000 $m^3/s$ |
| SEF (RMF+△)[4] | 6 250 $m^3/s$ |
| Spillway capacity (existing) | 3 484 $m^3/s$ |
| Spillway capacity (new) | 4 159 $m^3/s$ |
| 1 Full supply level 2 Non-overspill crest 3 Recommended design flood<br>4 Safety evaluation flood (regional maximum flood) | |
| Source: Badenhorst and van Wyk (2008) | |

The following information was obtained from the monthly reports and cost report:

**Total area of parapet as per payment certificate:** 1 803 $m^2$

**Total length of parapet wall as per design report:**

| | |
|---|---|
| Right embankment | 1 466.2 m |
| Left embankment | 304.2 m |
| **Total** | 1 770.4 m |

**Parapet wall cost:** ZAR3 908 744

**Actual unit price:** ZAR2 168/$m^2$

The client insisted that local labour be used on this contract. This led to a dispute between the contractor and the client as the contractor believed that the client was responsible for funding the training component of the project. Due to the use of local unskilled labour, many parts of the brickwork were rejected by the engineer and the contractor had to pay for redoing the work at his own cost.

According to Dr R Dube, the project manager, the following man-hours can be allocated to the brick parapet wall project (Table 3.6):

**Table 3.6: Albert Falls Dam man-hours for brick parapet wall**

| Date | Number of persons employed | Days | Hours | Man-hours |
|---|---|---|---|---|
| November 2009 | 13 | 23 | 8 | 2 392 |
| December 2009 | 13 | 10 | 8 | 1 040 |
| January 2010 | 17 | 17 | 8 | 2 312 |
| February 2010 | 25 | 23 | 8 | 4 600 |
| March 2010 | 25 | 20 | 8 | 4 000 |
| April 2010 | 7 | 15 | 8 | 840 |
| **TOTAL** | | | | **15 184** |

Due to the nature of brickwork, it was decided to use $m^2$ and not $m^3$ because the brickwork is a relatively 'slender' structure. The parapet wall was also priced in $m^2$ in the bill of quantities.

Using 15 184 man-hours to create 1803 $m^2$ of brick parapet wall equates to 8.42 man-hours/$m^2$ of parapet wall.

| | |
|---|---|
| **Total number of man-hours worked on the parapet wall project** | 15 184 man-hours |
| **Total area of brickwork laid** | 1 803 $m^2$ |
| **Labour opportunities in man-hours/$m^2$** | 15 184 man-hours/1 803 $m^2$ = **8.42 man-hours/$m^2$** |

Photographs of the Albert Falls Dam parapet wall during and after construction are shown in Figures 3.20 and 3.21.



**Figure 3.20: Albert Falls Dam during construction of the parapet wall**



**Figure 3.21: Albert Falls Dam completed parapet wall**

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Having presented the salient information in Chapter 3 for each of the five dams studied, a discussion of the findings is presented in Chapter 4.

# 4 Discussion of findings

Having presented the research methodology and the findings in Chapter 3, the findings are discussed in Sections 4.1 and 4.2. The lessons learnt from the labour-intensive projects studied are discussed in Section 4.3.

## 4.1 Rubble masonry concrete structure comparison and discussion

The dams researched varied in many ways according to the contractors constructing it, the types of materials used and the quantities of material used. The values of projects that were completed before 2012 were inflated by the annual consumer price index to arrive at the 2012 values. The annual consumer price index figures were obtained from www.inflation.eu (2013). The comparative key information regarding the rehabilitated dams is summarised in Table 4.1.

**Table 4.1: Comparison of rubble masonry concrete structures with a conventional concrete structure**

| Project | Contractor | Material | Quantity placed ($m^3$) | Cost (ZAR/$m^3$) | Adjusted cost (ZAR/$m^3$) | Job opportunities (man-hours/$m^3$) | Productivity ($m^3$/ person/day) |
|---|---|---|---|---|---|---|---|
| Molepo Dam Spillway | DWA: Construction | RMC | 20 413 | 1 943 | 2 246 | 20 | 0.47 |
| Chuniespoort Dam Spillway | DWA: Construction | RMC | 8 480 | 2 203 | 2 203 | 36 | 0.36 |
| Chuniespoort Dam Parapet Wall | DWA: Construction | RMC | 1 060 | 2 203 | 2 203 | 30 | 0.32 |
| Mashashane Dam Spillway | Stefanutti Stocks | RMC | 1 790 | 1 048 | 1 164 | 20 | 0.72 |
| Klein Maricopoort Dam Spillway | DWA: Construction | Conventional mass concrete | 10 465 | 2 390 | 2 527 | 22 | N/A |

### 4.1.1 Production

A plot of the number of man-hours per $m^3$ for RMC structures is shown in Figure 4.1.

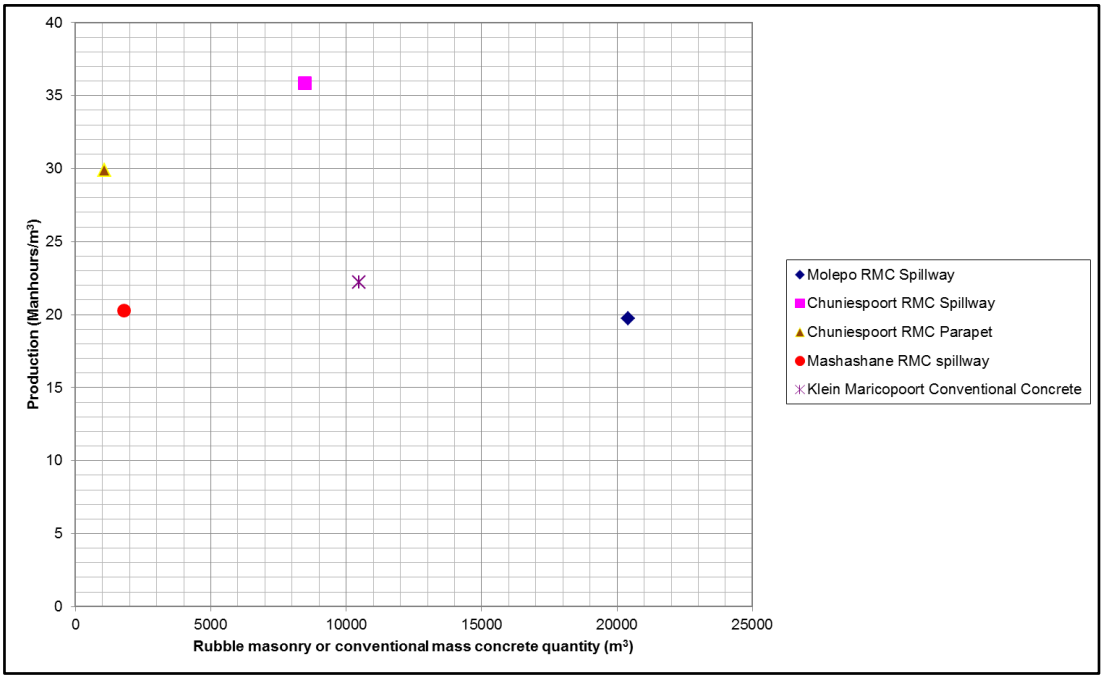


**Figure 4.1: Man-hours/$m^3$ for rubble masonry concrete and conventional concrete**

Figure 4.1 illustrates that for RMC structures between 20 man-hours/$m^3$ and 36 man-hours/$m^3$ were created for dam rehabilitation projects. No significant trend can be seen from this figure as there are too many variables that can influence the rate of production (for example, the quantity of RMC placed, the design and the contractor).

From Figure 4.1 it can be seen that the quantity of RMC placed at Molepo Dam (20 413 $m^3$) is much greater than the quantities of RMC placed at the other dams. The number of man-hours/$m^3$ is also the lowest (just below 20 man-hours/$m^3$) compared with the other structures. The reason for this is that bigger structures do not necessarily create more labour opportunities per $m^3$ of RMC placed because large rocks/boulders serve the purpose of the hearting rubble material.

It can, however, be derived that a relatively similar quantity of conventional concrete placed at Klein Maricopoort (10 465 $m^3$) generated 22 man-hours/$m^3$ of employment compared with the construction of the RMC spillway at Chuniespoort Dam (8 480 $m^3$) which generated 36 man-hours/$m^3$ of employment – a 63 % increase in labour opportunities per $m^3$.

### 4.1.2 Cost

A cost comparison for RMC projects and conventional concrete projects (adjusted to the 2012 cost) is shown in Figure 4.2.

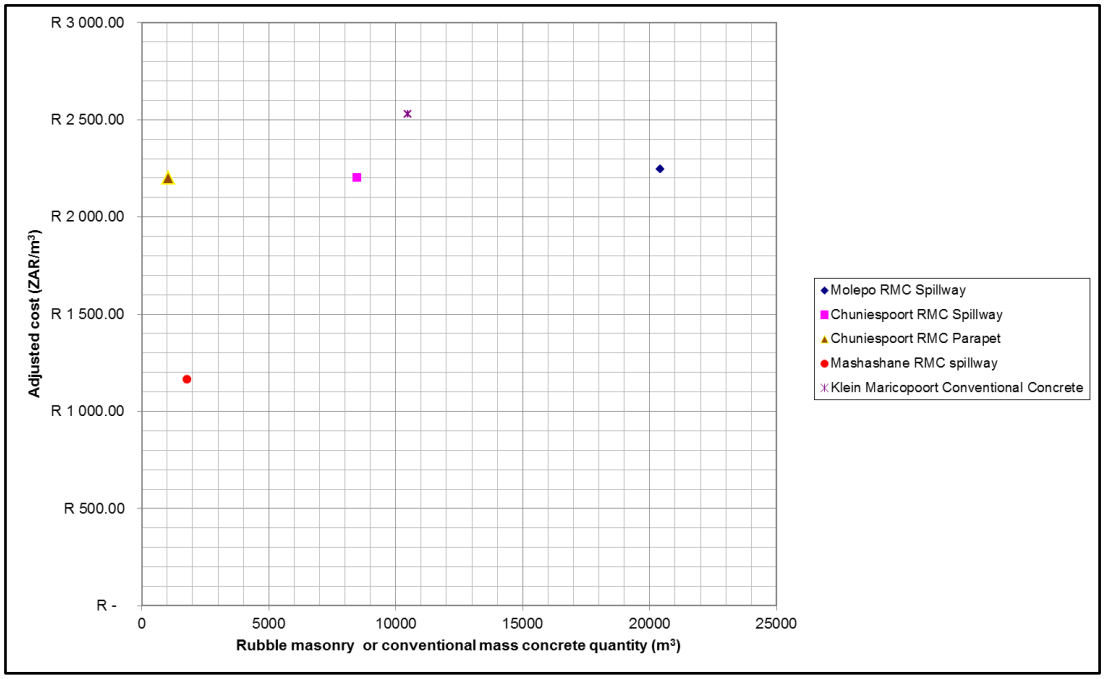


**Figure 4.2: Cost comparison for rubble masonry concrete projects and conventional concrete projects (adjusted to 2012 cost)**

From Figure 4.2 it can be seen that for DWA: Construction the adjusted cost of RMC varies between R2 203 and R2 246/$m^3$. This compares favourably with the DWA: Construction cost of R2 527/$m^3$ for conventional concrete at Klein Maricopoort Dam. It should, however, be noted that at Chuniespoort Dam the rock was obtained free of charge from the mine and only hauling cost was necessary. At Molepo Dam, the rock was obtained from the area, but with costs for blasting and transporting the material.

At Mashashane Dam the construction was done by a private contractor. The cost/$m^3$ is much lower when compared with RMC projects where DWA: Construction is the contractor. Possible reasons for the private sector contractor being less costly may be due to different remuneration rates between DWA: Construction and the private contractor. DWA: Construction pays labour rates as specified by the South African Federation for Civil Engineering Contractors. The private contractor appointed at Mashashane dam needed a relatively small quantity of rock (1 790 $m^3$) which was obtained from the vicinity. The concrete mixing plant was able to set up close to the actual RMC construction area, all factors that warrant a lower price.

In contrast, DWA: Construction must comply with the Department of Water Affairs' supply chain management regulations, although the supply chain management regulations were never intended for construction of major civil infrastructure. The fact that the same rules apply for buying stationery in the Department as for procuring large items like tonnes of cement is handi-capping the Department's Construction teams in terms of competitiveness with the private sector. The procurement of items has long lead times as tenders above R500 000 must be advertised on an open tender basis compared with private contractors who do not have these constraints. This also limits the Department's Construction units from negotiating bulk savings and building up good working relationships with their suppliers.

### 4.1.3 Productivity

The productivity rates of RMC projects are shown in Figure 4.3.

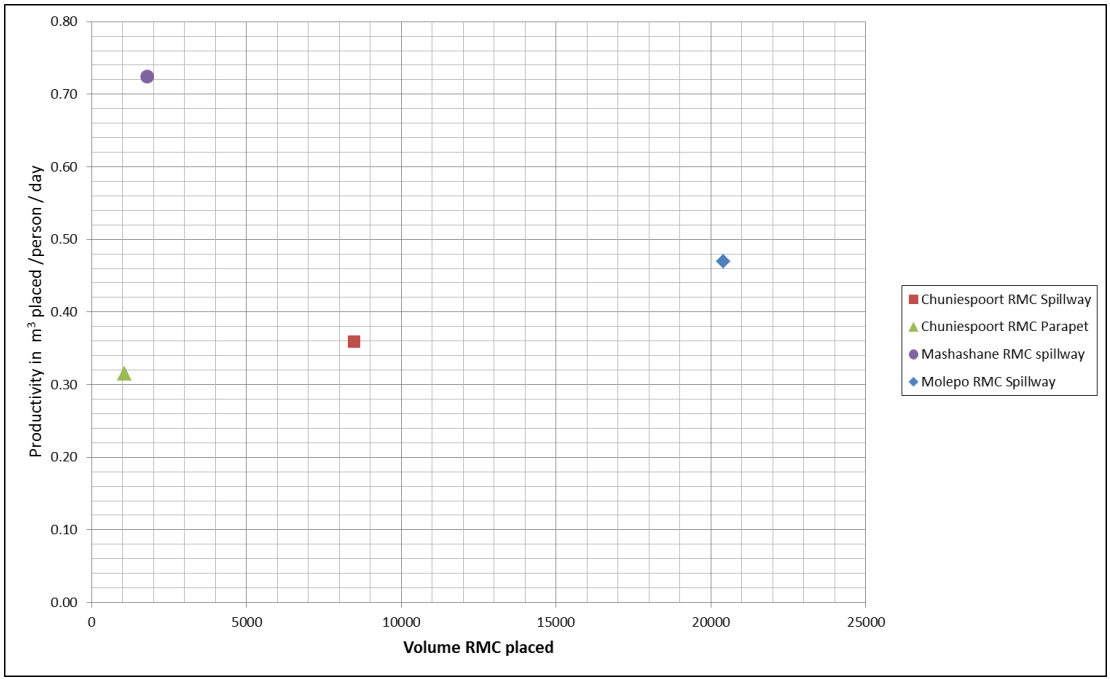


**Figure 4.3: Productivity rates of rubble masonry concrete projects**

When calculating the productivity, only the contributions of the labourers who placed the RMC were taken into account.

From Figure 4.3 it can be seen that productivity on the rehabilitated RMC dams varies between 0.32 $m^3$/person/day to 0.72 $m^3$/person/day.

When comparing RMC projects to the CIDB's (2005) statement that productivity rates vary widely from as little as 0.3 $m^3$/person/day to 5 $m^3$/person/day, it can be seen that the DWA: Construction projects at Chuniespoort Dam are at the bottom end of this range. Given that DWA: Construction is using machinery to transport the rock and batching plants to mix the concrete, the productivity should be well above the minimum 0.3 $m^3$/person/day mark. The CIDB, however, is not clear as to how they calculate their figures and whether these rates are estimates or based on actual production figures. It might be that CIDB's (2005) figures are based on the construction of new RMC dams. Rehabilitation and construction work on existing dams is known to be more complex than building a new dam. Reasons for this phenomenon vary from a lack of as-built drawings – especially on dams built by the former "homelands" – to working space constraints when working with existing structures.

When considering productivity, Mashashane Dam's rehabilitation (at 0.7 $m^3$/person/day) stands out as it is much greater than the rate achieved at Chuniespoort Dam (0.36 $m^3$/person/day) and Molepo Dam (0.47 $m^3$/ person/day).

The reasons for the above differences in productivity rates are that the private contractor and DWA: Construction do not have a "level base" from which to make comparisons.

The private sector contractor can appoint any individual it deems fit for the project to bolster their human resources capacity whereas the in-house public sector contractor is governed by Public Service Acts and Regulations. The same applies to incentive schemes that are one of the most important elements to increase productivity as illustrated when comparing the Chuniespoort Dam spillway and parapet wall projects. Although an incentive scheme was applied on the parapet wall section by means of creative manipulation of the rules and regulations, the flexibility to introduce incentive schemes (for example, bonuses) is not available to the in-house public sector contractor's site agents. DWA: Construction teams also have a limited number of professional employees and are required to advertise and fill their posts in a similar manner as a normal Government department conforming with Public Service regulations whereas a private contractor can buy the best skills that suit its business model and offer him/her a salary without being bound by set salary levels.

DWA: Construction starts with new team members at each construction site because it is a prerequisite to use local labour at the different construction sites. In contrast, private contractors can create an experienced dam-building team and can relocate this team from one dam site to another, retaining core specialities that can mentor new labourers elsewhere.

Figure 4.4 shows the productivity chart for DWA: Construction RMC sites. The trend line has been added to indicate a linear productivity rate based on the volume of RMC placed and figures obtained from Molepo Dam and Chuniespoort Dam's spillways without incentive schemes. This positive line is

to be expected as projects are normally more productive with increased quantities.

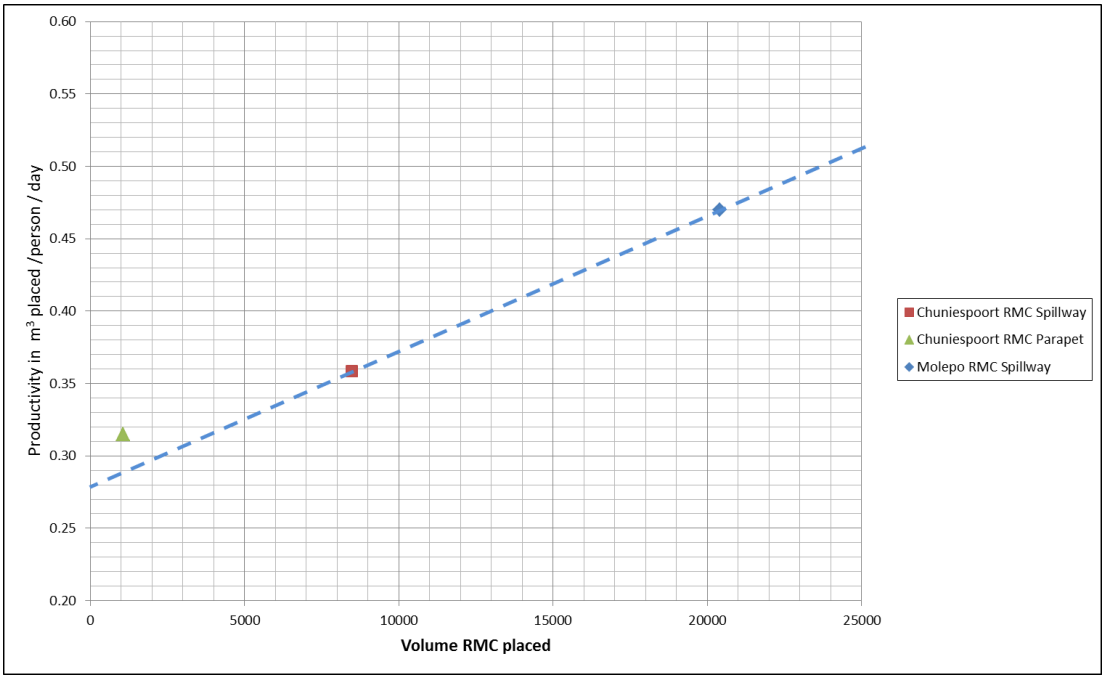


**Figure 4.4: Productivity rates and trend line for rubble masonry concrete structures constructed by DWA: Construction**

From Figure 4.4 it can be observed that the productivity rate for Chuniespoort Dam's RMC parapet wall lies above the trend line. The staff had an incentive scheme on the parapet wall project which led to significantly faster placement rates in order to be awarded greater remuneration or free time. The faster placement rate had no impact on the quality of the product. The nature of constructing a parapet wall requires more effort and workmanship than construction of a spillway (with its concomitant large volumes) as no dumping of mass rock is possible as would be the case on a larger RMC structure. Despite the more difficult construction methods for a parapet wall, the productivity decreased from 0.36 $m^3$/person/day for the RMC spillway to only 0.32 $m^3$/person/day for the RMC parapet wall.

Many appurtenant structures were built on RMC sites which indicate that the labourers can use the skills they have learnt to build structures other than dams. These include the pump house at Molepo Dam, the entertainment (fireplace) facilities at Chuniespoort Dam, surface drains at Chuniespoort

Dam and walls similar to the parapet walls constructed. After completion of Molepo Dam, two labourers built two houses using the skills obtained from the project.

## 4.2 Parapet wall comparison and discussion

Chuniespoort Dam and Albert Falls Dam each had a parapet wall in their designs. The parapet wall at Chuniespoort Dam was constructed using RMC, while the parapet wall at Albert Falls Dam was constructed from bricks. The parapet wall at Chuniespoort was constructed by Department of Water Affairs: Construction who had an experienced team doing the work with an incentive scheme, whilst the parapet wall at Albert Falls was constructed by Structocon Civils cc, a private contractor,

Due to the different design materials and features of the two parapet walls – the one being a bulky RMC structure with a large volume of material and the other a slender brick wall structure with very little volume – it was decided that a fair comparison in terms of jobs created per $m^3$ was not possible. The researcher at one stage converted the volume ($m^3$) of RMC placed, into the area ($m^2$) facing the upstream side but, after careful consideration, the results were not considered to be fair and reasonable. For completeness the results of the cost and labour used are shown in Table 4.2 as both projects were done with the maximisation of labour opportunities in mind.

**Table 4.2: Parapet wall comparison**

| Project | Material | Area facing upstream ($m^2$) | Man-hours/$m^2$ | Cost ZAR | Cost/$m^2$ ZAR | Adjusted cost/$m^2$ |
|---|---|---|---|---|---|---|
| Chuniespoort Dam parapet wall | RMC | 1 122 | 28.2 | R5 431 700 | R4 841 | R4 841 |
| Albert Falls Dam parapet wall | Brick | 1 803 | 8.4 | R4 391 864 | R2 168 | R2 436 |

## 4.3 Lessons learnt from the labour-intensive dam rehabilitation projects

Several lessons may be learnt from the labour-intensive projects studied:

From the Molepo Dam RMC spillway construction (Section 3.2), it was learnt that care should be taken to ensure that sufficient rubble material for RMC projects is available on or near site. This will reduce excessive spending on hauling of materials and keep project costs low.

Incentive schemes – as in the Chuniespoort Dam RMC parapet wall construction project (Section 3.3.4) – motivate employees to complete the work in the shortest possible time. Without incentive schemes, productivity can decline to stretch the project to the maximum time possible in order for the workforce to remain employed for longer periods.

Training is a large component in construction of RMC structures. From the contractual disputes on the Albert Falls Dam brick parapet wall construction (Section 3.6), it was learnt that the client needs to ensure that there are sufficient funds in the bill of quantities for training. Project managers need to allow for the training component in the project programme.

In summary, RMC structures are not to be viewed as a “quick fix” solution that can be used on all future rehabilitation projects. It should be borne in mind that RMC structures can be built only in areas where sufficient labour and material are available. Above all, the design should be technically feasible. Each dam rehabilitation project needs to be considered carefully to verify its feasibility.

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Chapter 4 contained a discussion of the findings on the labour-intensive construction projects studied, comparing labour-intensive construction methods with conventional construction methods. It concluded with a section on the lessons learnt from labour-intensive projects. The final chapter contains the conclusions and recommendations for further research.

# 5 Conclusions and recommendations for further research

This chapter, the final chapter of the research report, presents the conclusions and recommendations for further research.

## 5.1 Conclusions

From the limited data available for rehabilitated dams it can be concluded that the cost of RMC structures is not only on par with costs per $m^3$ of conventional concrete, but they also create more job opportunities in man-hours/$m^3$ placed. One must, however, be careful to consider not only man-hours/$m^3$ as work can be slowed down deliberately to have employment for longer. By measuring productivity, the efficiency of a project can be ascertained. In terms of productivity a large gap exists between the productivity rates obtained from the private sector and the public sector (DWA: Construction). An effort should be made to increase the productivity rates of future DWA: Construction RMC projects by addressing the stumbling blocks that currently hamper efficient construction by the in-house public sector contractor.

Although in this research project, RMC was found to be less expensive than its conventional concrete counterpart, the full design of future dam rehabilitation structures should be priced and compared on a project-by-project basis as various factors (for example, material and labour availability) play a role in the success of the project.

The successful application of an incentive scheme proved that a significant increase in production can be achieved on labour-intensive projects when the correct tools are available.

As far as can be ascertained, the information obtained from this comparative study has not been documented previously and thus it may be useful as a

baseline study against which to assess labour-intensive dam rehabilitation projects being undertaken in South Africa.

The research concludes that labour-intensive rehabilitation of dams should be continued since it results in a technically sound and cost-competitive product and creates more productive labour opportunities per unit of expenditure.

## 5.2 Recommendations for further research

This research project has revealed several aspects that warrant further probing:

- Based on the good quality of appurtenant structures constructed using RMC (for example “braai” (outdoor cooking) facilities, houses and surface drains), the experienced RMC gangs can be taught entrepreneurial skills in order to use their skills to start their own businesses.
- Ways to increase productivity within the Public Service Acts and Regulations need to be explored where DWA: Construction is the contractor on RMC projects.
- The job opportunities created on mechanically stabilised earth structures should be investigated for possible future comparisons.

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